

Assessment of the Equivalency of Three-Run
Relative Accuracy Audits Versus Six-Run
Relative Accuracy Audits for Characterizing CEMS
(Continuous Emission Monitoring Systems) Performance

Entropy Environmentalists, Inc.
Research Triangle Park, NC

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ASSESSMENT OF THE EQUIVALENCY OF THREE-RUN RELATIVE ACCURACY AUDITS
VERSUS SIX-RUN RELATIVE ACCURACY AUDITS FOR CHARACTERIZING CEMS PERFORMANCE

by

J. Ron Jernigan
Entropy Environmentalists, Inc.
Research Triangle Park, NC 27711

Roosevelt Rollins
Environmental Monitoring Systems Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

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ENVIRONMENTAL MONITORING SYSTEMS LABORATORY
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J. Ron Jernigan, P.E.
CEM/Engineering Division
Entropy Environmentalists, Inc.
P. O. Box 12291
Research Triangle Park, North Carolina 27709

Roosevelt Rollins
Quality Assurance Division
Environmental Monitoring Systems Laboratory
United States Environmental Protection Agency
Research Triangle Park, North Carolina 27711

On March 14, 1984, "Appendix F, Quality Assurance Procedures: Procedure 1 - Quality Assurance Requirements for Gas Continuous Emission Monitoring Systems (CEMS) for Compliance" was proposed for inclusion in 40 CFR 60. Several commenters on the proposal package requested that three-run relative accuracy audits without the 2.5 percent error confidence coefficient be allowed in lieu of the proposed six-run relative accuracy audit. This paper compares the equivalency of three-run versus six-run relative accuracy audits for characterizing gas CEMS performance, utilizing a tentative three-run relative accuracy criterion of $\leq 15\%$ applied to test data compiled under the EPA-funded field audit program to evaluate the adequacy and effectiveness of the Procedure 1 quality assurance requirements.

When all of the six-run SO_2 and NO_x RAA data from the EPA audit program were considered, the results of this comparison indicate that the three-run, $\leq 15\%$ criterion was slightly more difficult to meet than was the six-run, $\leq 25\%$ criterion. However, when only the six-run SO_2 and NO_x RAA data with relative accuracy results of less than 25% were considered, the results of this comparison indicate that the three-run, $\leq 15\%$ criterion was approximately equivalent to the six-run, $\leq 25\%$ criterion.

ASSESSMENT OF THE EQUIVALENCY OF THREE-RUN
RELATIVE ACCURACY AUDITS VERSUS SIX-RUN
RELATIVE ACCURACY AUDITS FOR
CHARACTERIZING CEMS PERFORMANCE

Introduction

On March 14, 1984, EPA proposed to add "Appendix F, Quality Assurance Procedures: Procedure 1 - Quality Assurance Requirements for Gas Continuous Emission Monitoring Systems (CEMS) for Compliance" (hereafter referred to as "Procedure 1") to 40 CFR 60. The proposed regulation applies to gas CEMS's that are used for demonstrating compliance with emission limitations (or percent control requirements) on a continuous basis.

Procedure 1 requires the owner/operator to perform quality assessment checks or audits at specific intervals to assess the accuracy and precision of the CEMS measurements. One of the specified quality assessment checks for characterizing gas CEMS performance is a six-run relative accuracy audit. Several commenters on the proposed Procedure 1 requested that three-run relative accuracy audits without the 2.5 percent error confidence coefficient be allowed in lieu of the proposed six-run test. This paper compares the equivalency of three-run versus six-run relative accuracy audits for characterizing CEMS performance, employing a three-run $\leq 15\%$ relative accuracy criterion calculated without a 2.5 percent error confidence interval. (The $\leq 15\%$ criterion was suggested by the EPA for the purposes of this comparison.)

This comparison is based on test data compiled under the EPA-funded field audit program to evaluate the adequacy and effectiveness of the Procedure 1 quality assurance requirements (hereafter referred to as the Appendix F audit program). This program entailed a total of 78 SO₂ and NO_x quarterly six-run relative accuracy audits (RAA's) performed at eight different sources. Relative accuracy testing for SO₂ was conducted at all eight sources, and for NO_x, at five of the eight sources. A data base consisting of 78 SO₂ and NO_x quarterly RAA's was evaluated in the assessment of the adequacy of three-run versus six-run RAA's. Initially, potential three-run RAA results were calculated from the entire data base and compared with the six-run results. Another comparison was then made between three-run and six-run results using a subset of the data base consisting of only those SO₂ and NO_x RAA's with six-run relative accuracy results of less than 25%; this subset consisted of 58 SO₂ and NO_x quarterly RAA's.

Data Evaluation Procedures

As a first step in this analysis, an example computer program was furnished by EPA. This program was modified to provide additional data and also to print out the desired information in the desired format (see Figure 1). The six-run RAA reference method and corresponding CEMS results of the 78 previously described SO₂ and NO_x CEMS audits were then input into the computer program. The data from each audit were identified by: source code, monitor type, test date, and six-run RAA results. Once the six-run RAA data had been input, the computer program then arranged the six individual sets of test run

3-Run RAA vs. 6-Run RAA

Source Code - A

Monitor System - DUPONT S02/02

Date - 11/25/81

6-Run RAA Results - 9.5 %

RUN NO.	REF. METHOD RESULTS lb/MMBtu	CEM RESULTS lb/MMBtu
1	0.46	0.50
2	0.50	0.53
3	0.60	0.59
4	0.57	0.61
5	0.63	0.67
6	0.67	0.72

OBS	TEST RUNS	REF. METHOD MEAN	CEM AV. DIFF.	3-RUN RAA %	TESTS Pass/Fail ALL CONSEC.
1	1 2 3	0.52	0.02	3.8 %	P P
2	1 2 4	0.51	0.04	7.8 %	P
3	1 2 5	0.53	0.04	7.5 %	P
4	1 2 6	0.54	0.04	7.4 %	P
5	1 3 4	0.54	0.02	3.7 %	P
6	1 3 5	0.56	0.02	3.6 %	P
7	1 3 6	0.58	0.03	5.2 %	P
8	1 4 5	0.55	0.04	7.3 %	P
9	1 4 6	0.57	0.04	7.0 %	P
10	1 5 6	0.59	0.04	6.8 %	P
11	2 3 4	0.56	0.02	3.6 %	P P
12	2 3 5	0.58	0.02	3.4 %	P
13	2 3 6	0.59	0.02	3.4 %	P
14	2 4 5	0.57	0.04	7.0 %	P
15	2 4 6	0.58	0.04	6.9 %	P
16	2 5 6	0.60	0.04	6.7 %	P
17	3 4 5	0.60	0.02	3.3 %	P P
18	3 4 6	0.61	0.03	4.9 %	P
19	3 5 6	0.63	0.03	4.8 %	P
20	4 5 6	0.62	0.04	6.5 %	P P

Total Obs. That Passed = 20 of 20 4 of 4

3-Run RAA Pass Specification < or = to 15 %

Figure 1.

data into 20 possible three-run combinations (i.e., the maximum possible observations). For each possible result, the applicable three test run combination was listed, and the following were then computed: the reference method mean (RM), the CEM average difference (d), and the three-run percent accuracy. The three-run accuracy results were calculated using the formula:

$$\% \text{ Accuracy} = \frac{d}{RM} \times 100\%$$

In addition, for each of the 20 observations listed in the computer analysis, each of the three-run results that met the applicable limit (i.e., $\leq 15\%$ for three runs) was assigned a value of "1," and each RAA result that did not meet the limit was assigned a value of "0." These results were then tabulated and evaluated in three ways: (1) using the first three runs of each six-run RAA; (2) using all possible three-run combinations of each six-run RAA (i.e., a total of 20 possible combinations), and (3) using the four sets of three consecutive RAA runs (i.e., Runs 1-3, Runs 2-4, Runs 3-5, and Runs 4-6) of each RAA. The "Pass" and "Fail" (i.e., 1 and 0) values were tabulated for each audit by the three methods previously described in order to determine the percent of the six-run RAA results that met the three-run limit, and the percent that failed to meet either the three-run or the six-run limit (see Tables 1 and 2).

In order to examine further the equivalency of the two criteria (i.e., $\leq 25\%$, $\leq 15\%$), several subsets of the data base were subjected to statistical analysis. The standard deviation and the maximum, minimum, average, and median relative accuracy were computed separately for both six-run and potential first-three-run results within the following data subsets:

- o All six-run SO_2 relative accuracy data
- o All six-run NO_x relative accuracy data
- o Six-run SO_2 relative accuracy data from tests where the six-run SO_2 relative accuracy was $< 25\%$
- o Six-run NO_x relative accuracy data from tests where the six-run NO_x relative accuracy was $< 25\%$

Figures 2 and 3 are graphical presentations of the results of these statistical analyses.

A final evaluation to determine the equivalency of the two criteria entailed adjusting (or normalizing) each of the results within the six-run data base comprised of relative accuracy results of $< 25\%$ to a relative accuracy of exactly 25% in order to determine whether the resultant adjusted three-run relative accuracy (using the first three runs) would approximate 15% , as would be expected if the two criteria were equivalent. The equation that follows was used in adjusting the data:

$$x = \frac{25 \times A}{B}$$

Where:

- x = adjusted three-run percent relative accuracy
- A = actual three-run percent relative accuracy
- B = actual six-run percent relative accuracy

TABLE 1.
THREE-RUN VS. SIX-RUN SO₂ RAA RESULTS
SUMMARY OF COMPUTER ANALYSIS

EACH PASS = 1 EACH FAIL = 0

Source Code	Six-Run Audit Date	Six-Run Results ($\leq 25\%$ Criterion)	First Three Runs (maximum=1)	All Three-Run Combinations (maximum=20)	Consecutive Runs (maximum=4)
A	01/81	1 (8.0%)	1 (5.1)	20	4
A	11/81	1 (9.5%)	1 (3.8)	20	4
A	04/82	1 (19.7%)	1 (14.6)	20	4
A	08/82	0 (34.7%)	0 (30.0)	0	0
A	04/83	1 (16.4%)	1 (7.8)	20	4
A	07/83	1 (18.7%)	0 (15.6)	16	2
A	11/83	0 (53.7%)	0 (46.7)	0	0
A	02/84	0 (29.3%)*	0 (32.0)	0	0
N	09/80	1 (18.8%)	1 (4.4)	20	4
N	07/81	1 (12.3%)	1 (4.4)	20	4
N	12/81	0 (128%)	0 (115.4)	0	0
N	03/82	0 (61.8%)	0 (44.8)	0	0
N	06/82	0 (146.8%)	0 (67.9)	0	0
N	09/82	0 (34.8%)	0 (26.8)	0	0
P	07/81	1 (12.3%)	1 (2.9)	20	4
S1	08/81	1 (18.6%)	0 (18.2)	17	2
S1	12/81	1 (8.9%)	1 (0.8)	20	4
S1	05/82	0 (26.7%)	0 (23.1)	0	0
S1	11/82	0 (35.9%)	0 (32.9)	0	0
S1	05/83	1 (12.2%)	1 (10.3)	20	4
S1	08/83	1 (22.0%)	0 (24.7)	0	0
S1	05/81	1 (16.0%)	1 (5.5)	20	4
S1	07/81	1 (13.6%)	1 (5.4)	20	4
S2	12/81	1 (6.5%)	1 (4.3)	20	4
S2	04/82	1 (11.3%)	1 (8.0)	20	4
S2	11/82	1 (23.1%)	1 (13.9)	7	2
S2	02/83	1 (5.1%)	1 (3.1)	20	4
S2	05/83	1 (12.2%)	1 (7.0)	20	4
S2	08/83	0 (12.0%)	1 (10.2)	20	4
C	05/83	0 (35.1%)*	1 (5.3)	10	1
C	08/83	1 (13.8%)	1 (5.5)	20	4
C	11/83	1 (2.1%)	1 (1.3)	20	4
C	02/84	0 (162.5%)	0 (160.9)	0	0
C	06/84	0 (45.2%)*	0 (34.4)	0	0
C	09/84	0 (29.0%)*	0 (16.7)	0	0
M	12/83 - C	1 (12.1%)	1 (4.4)	20	4
M	03/84 - C	0 (42.8%)	0 (46.0)	0	0
M	07/84 - C	1 (6.6%)	1 (6.0)	20	4
M	12/83 - T	1 (15.5%)	1 (10.5)	20	4
M	03/84 - T	1 (17.2%)	1 (12.6)	20	4
M	07/84 - T	0 (25.8%)	0 (22.6)	0	0
W	08/83 - I	1 (13.8%)	1 (14.1)	20	4
W	01/84 - I	1 (6.0%)	1 (3.9)	20	4
W	03/84 - I	1 (14.0%)	1 (9.2)	20	4
W	07/84 - I	1 (13.5%)	1 (9.5)	20	4
W	01/84 - O	1 (6.7%)	1 (5.9)	20	4
W	03/84 - O	1 (2.6%)	1 (0.0)	20	4
TOTAL PASSES:		32 (68%)	30 (64%)	610 (65%)	119 (63%)
TOTAL POSSIBLE:		47	47	940	188
TOTAL FAILURES:		15 (32%)	17 (36%)	330 (35%)	69 (37%)

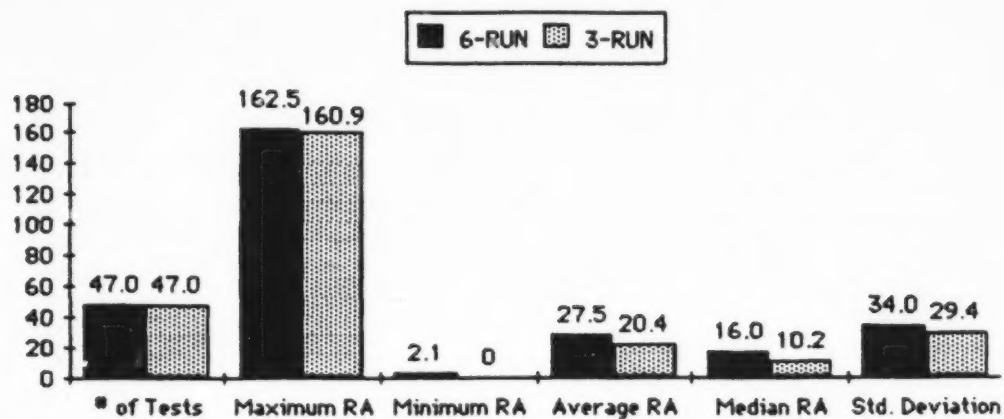
*These tests passed when using 10% of standard RA option.

TABLE 2.
THREE-RUN VS. SIX-RUN NO. RAA RESULTS
SUMMARY OF COMPUTER ANALYSIS

EACH PASS = 1 EACH FAIL = 0

Source Code	Six-Run Audit Date	Six-Run Results (<u>< 25% Criterion</u>)	Three-Run Results (<u>< 15% Criterion</u>)		
			First Three Runs (maximum=1)	All Three-run Combinations (maximum=20)	Consecutive Runs (maximum=4)
S1	8/81	1 (4.3%)	1 (2.7)	20	4
S1	12/81	1 (22.9%)	1 (3.6)	16	4
S1	5/82	1 (16.4%)	1 (13.5)	20	4
S1	11/82	1 (10.8%)	1 (5.5)	20	4
S1	05/83	0 (25.9%)	0 (22.8)	4	1
S1	08/83	1 (9.0%)	1 (6.9)	20	4
S1	05/81	1 (14.4%)	1 (7.4)	20	4
S1	07/81	1 (6.8%)	1 (3.1)	20	4
S2	12/81	0 (30.6%)	0 (22.4)	4	1
S2	04/82	1 (11.6%)	1 (5.1)	20	4
S2	11/82	1 (19.7%)	0 (15.4)	17	3
S2	02/83	1 (12.8%)	1 (10.3)	20	4
S2	05/83	1 (13.8%)	1 (11.4)	20	4
S2	08/83	1 (6.6%)	1 (3.1)	20	4
C	05/83	0 (36.2%)	0 (32.3)	0	0
C	08/83	0 (37.4%)	0 (28.3)	0	0
C	11/83	1 (16.5%)	0 (15.5)	14	2
C	02/84	1 (18.6%)	1 (2.5)	19	3
C	09/84	1 (14.6%)	1 (4.3)	20	4
M	12/83 - C	1 (23.9%)	0 (18.2)	0	0
M	03/84 - C	1 (12.8%)	1 (10.5)	20	4
M	07/84 - C	1 (20.2%)	0 (15.4)	18	3
M	12/83 - T	1 (13.4%)	1 (9.1)	20	4
M	03/84 - T	1 (7.8%)	1 (3.5)	20	4
M	07/84 - T	0 (27.2%)	0 (20.0)	0	0
W	08/83 - I	1 (21.0%)	1 (3.8)	20	4
W	01/84 - I	1 (9.8%)	1 (7.8)	20	4
W	03/84 - I	1 (19.5%)	1 (7.1)	16	3
W	07/84 - I	1 (8.1%)	1 (5.4)	20	4
W	01/84 - O	1 (9.5%)	1 (9.5)	20	4
W	03/84 - O	1 (11.5%)	1 (10.3)	20	4
TOTAL PASSES:		26 (84%)	22 (71%)	488 (79%)	96 (77%)
TOTAL POSSIBLE:		31	31	620	124
TOTAL FAILURES:		5 (16%)	9 (29%)	132 (21%)	28 (23%)

STATISTICAL ANALYSIS
ALL 6-RUN AND 3-RUN
SO₂ DATA



STATISTICAL ANALYSIS
ALL 6-RUN AND 3-RUN
NO_x DATA

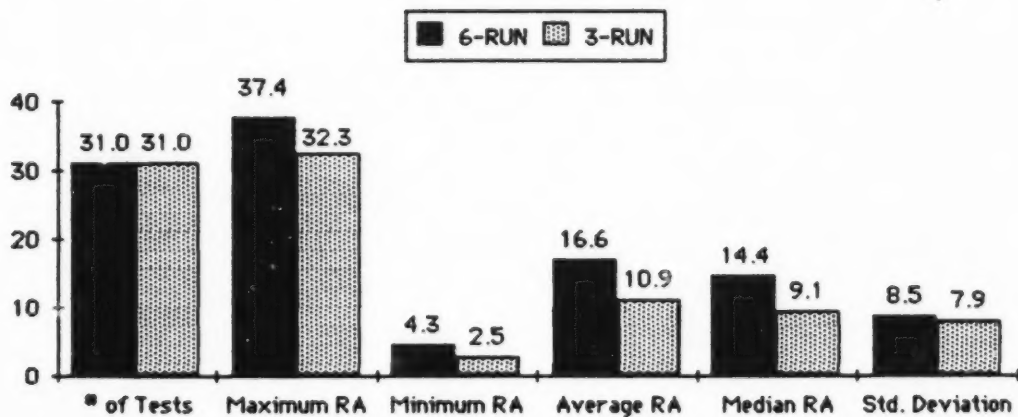
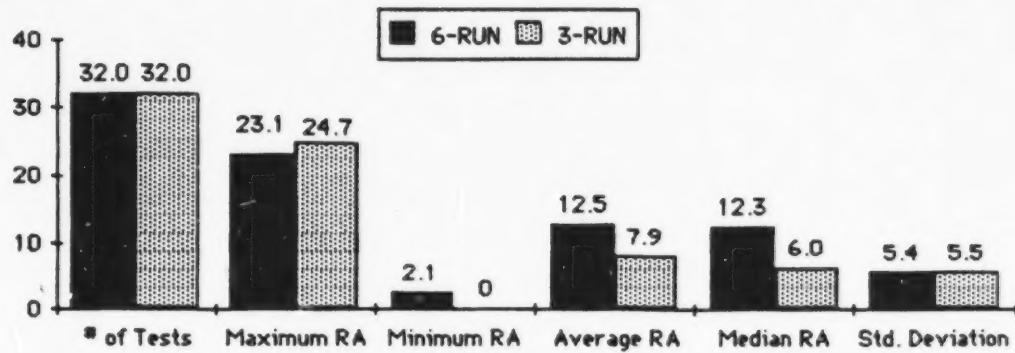


FIGURE 2.

STATISTICAL ANALYSIS
6-RUN AND 3-RUN RAA RESULTS
SO₂ RAA DATA < 25%



STATISTICAL ANALYSIS
6-RUN AND 3-RUN RAA RESULTS
NO_x RAA DATA < 25%

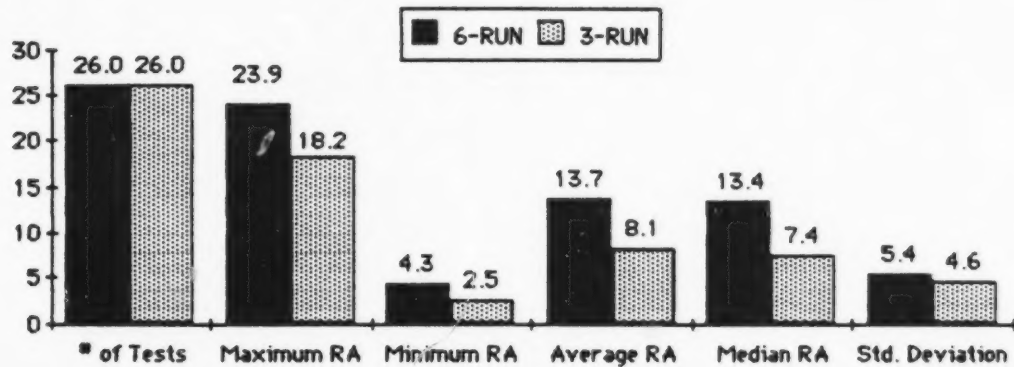


FIGURE 3.

Example: A = 5.1 %; B = 8.0 %

$$x = \frac{25 \times 5.1}{8.0}$$

$$x = 15.9 \%$$

The results of this evaluation were then subjected to statistical analysis; the results are presented graphically in Figure 4.

Discussion Of Results

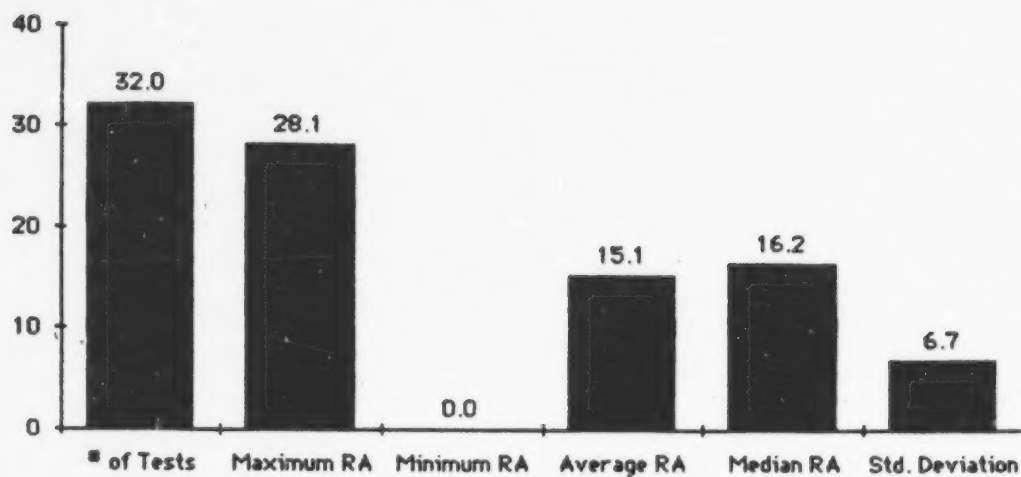
A total of 47 SO₂ and 31 NO_x quarterly six-run RAA's were evaluated (i.e., all of the data available from the Appendix F audit program), and comparisons of the percent of the SO₂ and NO_x CEMS's meeting six-run and three-run criteria are presented in Tables 1 and 2, respectively. These results indicate that, when all of the data are considered, the < 15% criterion for three runs was slightly more difficult to achieve than was the < 25% criterion for six runs.

Tables 1 and 2 show that a higher percent of both SO₂ and NO_x CEMS's met the six-run relative accuracy criterion than met the three-run criterion, regardless of which combination of three runs was considered. A comparison of the six-run results with the three-run results using only the first three runs shows that 4% of the SO₂ and 13% of the NO_x CEMS's that met the six-run criterion would not meet the three-run criterion. A comparison of the six-run results with the three-run results from all possible three-run combinations shows that 3% of the SO₂ CEMS's that met the six-run criterion would not meet the three-run criterion, and that 5% of the NO_x CEMS's that met the six-run criterion would not meet the three-run criterion. When the six-run results are compared with three-run results from consecutive runs, 5% of the SO₂ CEMS's that met the six-run criterion would not meet the three-run criterion, and 7% of the NO_x CEMS's that met the six-run criterion would not meet the three-run criterion. Thus, in this test sample, for SO₂ CEMS's, the largest difference in results is observed using only the results from consecutive runs, and for NO_x CEMS's, the largest disparity occurs when results from the first three runs are used.

The results of the statistical analysis conducted on the data subsets described above are presented in Figures 2-4. Figure 2 illustrates the results of the analysis conducted using all SO₂ and NO_x six-run relative accuracy data. Figure 3 illustrates the results of the analysis conducted using SO₂ and NO_x six-run relative accuracy data from tests where the six-run relative accuracy results were less than 25%. Both Figures 2 and 3 present also statistical information on the potential three-run results computed using the first three runs of each applicable six-run test included in the respective data bases.

Figure 2 in which all six-run data are shown, indicates graphically the same results seen in Tables 1 and 2; this analysis seems to indicate that the six-run, < 25% criterion is slightly more difficult to achieve than the three-run, < 15% criterion. When we examine the "Average RA" for SO₂ and NO_x, we see that the average six-run results represent a considerably smaller percentage of the applicable criterion than do the three-run results. For

STATISTICAL ANALYSIS
3-RUN RAA RESULTS
ADJUSTED 3-RUN SO₂ DATA



STATISTICAL ANALYSIS
3-RUN RAA RESULTS
ADJUSTED 3-RUN NO_x DATA

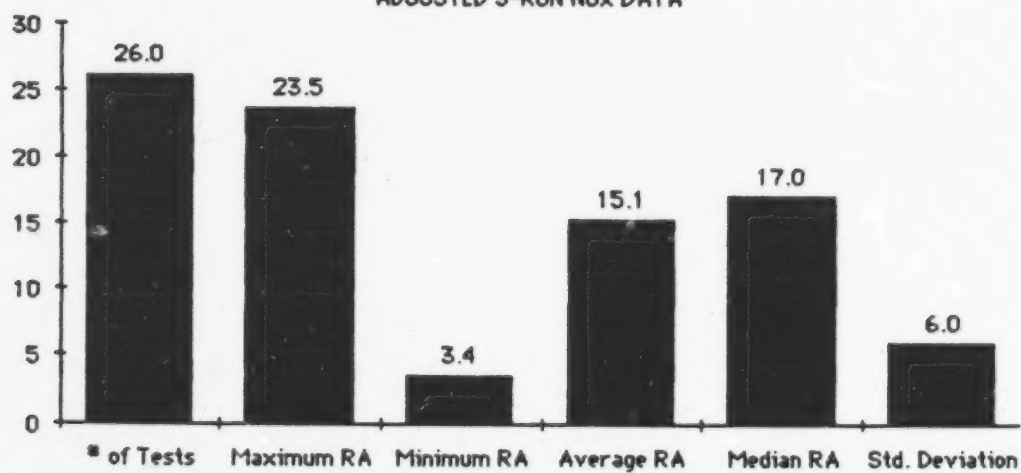


FIGURE 4.

SO₂, the average six-run relative accuracy (i.e. 27.5%) is 110% of the 25% criterion, while the average three-run relative accuracy (i.e., 20.4%) is 136% of the 15% criterion; thus, the average three-run relative accuracy appears to be more in excess of the three-run limit than is the average six-run relative accuracy with respect to the six-run limit. For NO_x, the same trend is evident, although the difference is less dramatic; the average six-run relative accuracy (i.e., 16.6%) represents 66.4% of the 25% criterion, while the average three-run relative accuracy (i.e., 10.9%) is 72.7% of the 15% criterion. This difference between three-run and six-run results may be partially due to skewing of the data resulting from the inclusion of such a diversity of relative accuracy results within the data base (i.e., relative accuracy results from 0.0 to 162.9%).

This difference appears to diminish in Figure 3, where only six-run relative accuracy results of less than 25% were included in the data base. Here we see the average six- and three-run relative accuracy results representing approximately the same proportion of the applicable criterion. For SO₂, the average six-run result (i.e., 12.5%) is 50.0% of the 25% criterion, while the average three-run result (i.e., 7.9%) is 52.7% of the 15% criterion. For NO_x, the average six-run result (i.e., 13.7%) is 54.8% of the 25% criterion, while the average three-run result (i.e. 8.1%) is 54.0% of the 15% criterion. This analysis indicates that the two criteria are approximately equivalent.

Figure 4 shows the normalized three-run relative accuracy results that occur when the six-run data from tests where the six-run relative accuracy result was less than 25% are adjusted upward to be exactly equivalent to 25%. If the methods and criteria are exactly equivalent, we would expect to see three-run relative accuracy results of 15% when the six-run relative accuracy results are 25%. As can be seen in Figure 4, the three-run normalized average relative accuracy results for SO₂ and NO_x are both 15.1%. Again, we can see that the $\leq 25\%$ criterion for six runs and the $\leq 15\%$ criterion for three runs are approximately equivalent.

Conclusion

The results of this evaluation support the conclusion that the proposed three-run relative accuracy criterion of $\leq 15\%$ calculated without a 2.5 percent error confidence interval is approximately equivalent to the existing six-run relative accuracy criterion of $\leq 25\%$.

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